USE OF EDIBLE OIL SUBSTRATE (EOS®) FOR IN SITU ANAEROBIC BIOREMEDIATION

Robert C. Borden
Solutions Industrial & Environmental Services, Inc.
3722 Benson Drive, Raleigh, NC 27609
Phone: (919) 873-1060, Email: rborden@solutions-ies.com

Coauthors:
Kapo M. Coulibaly, North Carolina State University
Yong Jung, North Carolina State University
Cameron M. Long, North Carolina State University
Nicholas L. Lindow, North Carolina State University,
Michael D. Lee, Terra Systems, Inc.
M. Tony Lieberman, Solutions Industrial & Environmental Services, Inc.
James R. Gonzales, Air Force Center for Environmental Excellence - ERT

Introduction

Recent laboratory and field studies have shown that injection of Edible Oil Substrate (EOS®) into the subsurface can provide an effective, low-cost alternative for the enhanced anaerobic bioremediation of chlorinated solvents, nitrate, perchlorate, acid mine drainage, and heavy metals. Many edible oils are insoluble in water and only slowly biodegradable under anaerobic conditions. As a consequence, these oils can provide an inexpensive, slow-release source of organic carbon for aquifer bioremediation.

In the EOS® process, emulsified food-grade soybean oil is injected into the aquifer to stimulate reductive dechlorination. Proprietary techniques are used to select the most appropriate oil and distribute it throughout the contaminated zone providing good contact between the oil and the chlorinated solvent. The edible oil then slowly dissolves over several years providing a carbon and energy source to accelerate the anaerobic biodegradation of the chlorinated solvents and other contaminants. All materials used in the process are Generally Recognized As Safe (GRAS), food-grade materials to aid in gaining regulatory approval for *in situ* application. The edible oil can be added to the treatment zone through conventional wells or using direct push technology to reduce costs. The EOS® process can be used to enhance pollutant biodegradation in a variety of situations.

- Source areas can be treated by injecting EOS® directly into 'hot spots'. As contaminant is slowly released from residual dense non-aqueous phase liquids (DNAPLs), the contaminant comes in contact with edible oil and is degraded, preventing downgradient migration of dissolved contaminants.

- Where a contaminant plume must be prevented from crossing a boundary, overlapping treatment zones can be created to prevent downgradient migration of the plume (see Figure 1).

- Where natural attenuation is not completely effective in controlling the migration of chlorinated solvents, EOS® can be distributed throughout the plume to supplement the naturally occurring organic carbon.

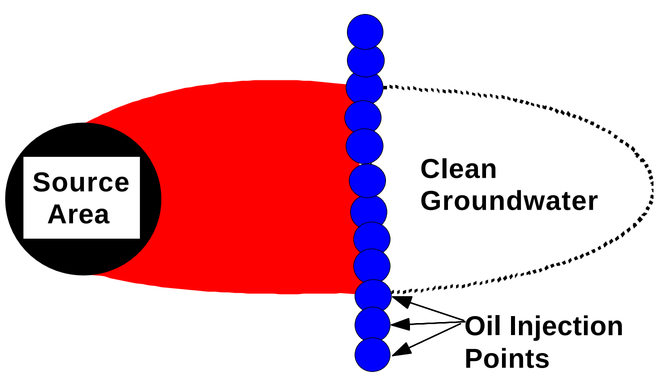

Figure 1. EOS® barrier constructed by injecting emulsified oil though a line of temporary or permanent injection points. EOS® slowly biodegrades over time providing a steady supply of organic carbon for anaerobic biodegradation of chlorinated solvents and other pollutants.

A series of laboratory and field studies have been conducted to develop methods to design and install *in situ* bioremediation systems using edible oils. Figure 2 shows results from laboratory microcosms constructed using aquifer material from a chlorinated solvent contaminated site in the North Carolina coastal plain that were amended with 500 mg/L of soybean oil. TCE and DCE were completely eliminated from all microcosm bottles within 50 days (Figure 2a). Vinyl chloride was produced then fully transformed to ethene after approximately 90 days. After sitting idle for one year, the microcosms were repeatedly respiked with PCE, but no more soybean oil was added. The results from the fifth respike with 20 mg/L PCE (120 µmole/L) are illustrated in Figure 2b. Immediately after respiking, the PCE concentration dropped to 13 µmole/L (~ 2.2 mg/L) due to sorption to the oil. The dissolved and sorbed PCE then rapidly transformed to TCE, then DCE, then VC and eventually to ethene. Every chlorinated compound (PCE, TCE, DCE, and VC) was degraded to below the analytical detection limit in every bottle within 50 days of the respike with compete conversion to ethene. It has now been over 3 years since soybean oil was added, and the chlorinated solvents still continue to rapidly biodegrade.

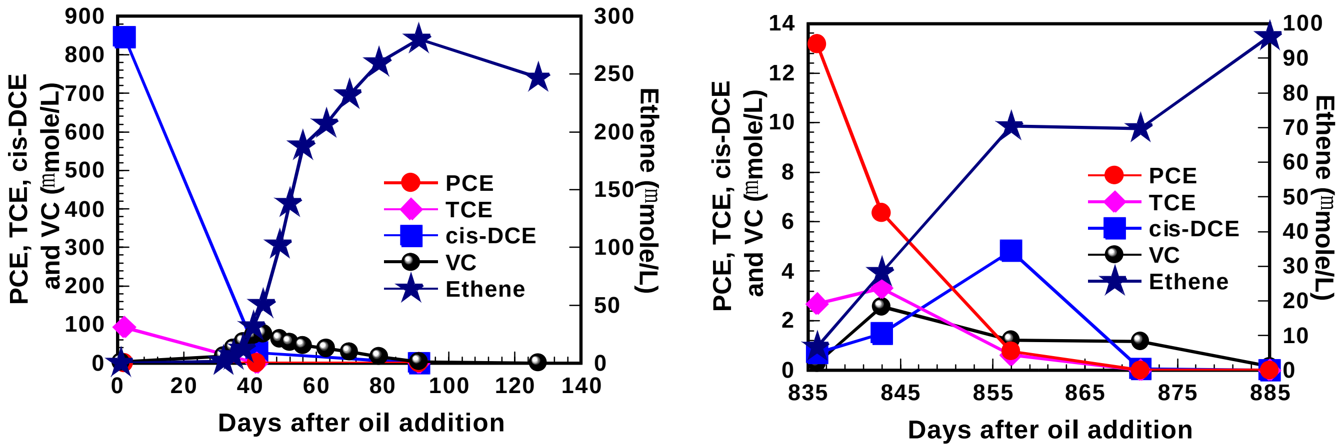

Figure 2. **Chlorinated solvent biodegradation in soil microcosms with 500 mg/L soybean oil: (a) initial degradation results; and (b) PCE degradation when respiked with 20 mg/L PCE at day 835. No additional oil was added to these bottles since they were originally constructed at day zero.**

Lab permeameter, 1-D column, 3-D sandbox, and mathematical modeling studies have been conducted to evaluate the transport and distribution of oil-in-water emulsions in sediments with varying clay and silt contents. The key to effective transport appears to be generating a stable oil-in-water emulsion with oil droplets that are: (1) smaller then the average sediment pore size; and (2) have favorable surface characteristics so the droplets do not stick too strongly to the sediment surface. Figure 3 shows results from a column test where a clayey sand was treated with 3 pore volumes (PV) of emulsified soybean oil followed by 7 PV of plain water. The emulsion is transported through the column with little attenuation. Hydraulic conductivity declines during the emulsion injection and then recovers to preinjection values during the post-injection water flush.

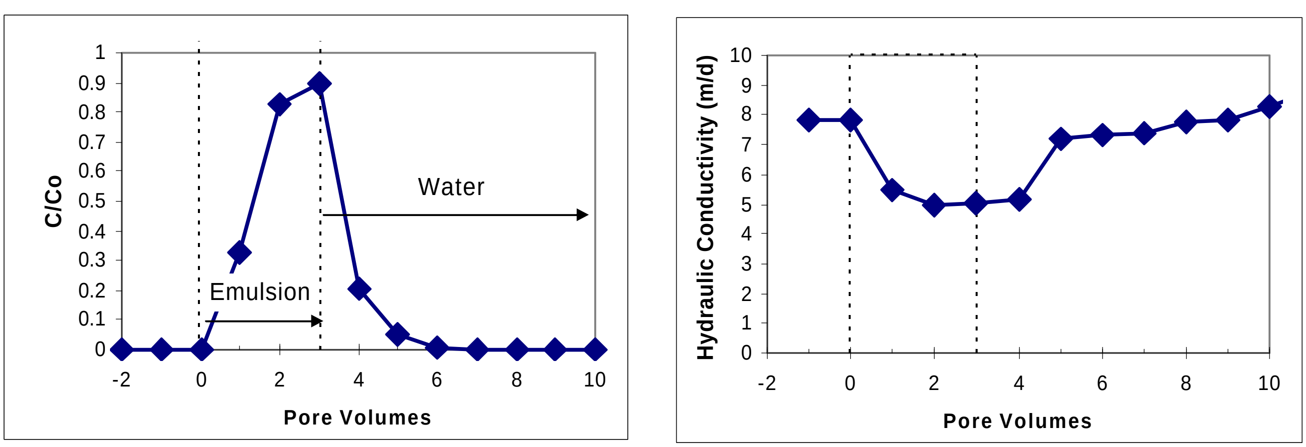

Figure 3 **Emulsion transport and associated changes in hydraulic conductivity during injection of field sand with 3 PV of oil-in-water emulsion followed by plain water.**

Similar results have been observed during emulsion injection tests conducted on other sands with varying clay content. Oil residual saturation (oil volume/pore volume) appears to be proportional to sediment clay content. Emulsion injection does result in some permeability loss. However, this loss is modest for most sediments (0 to 40% loss) and should not adversely affect the performance of a properly designed barrier.

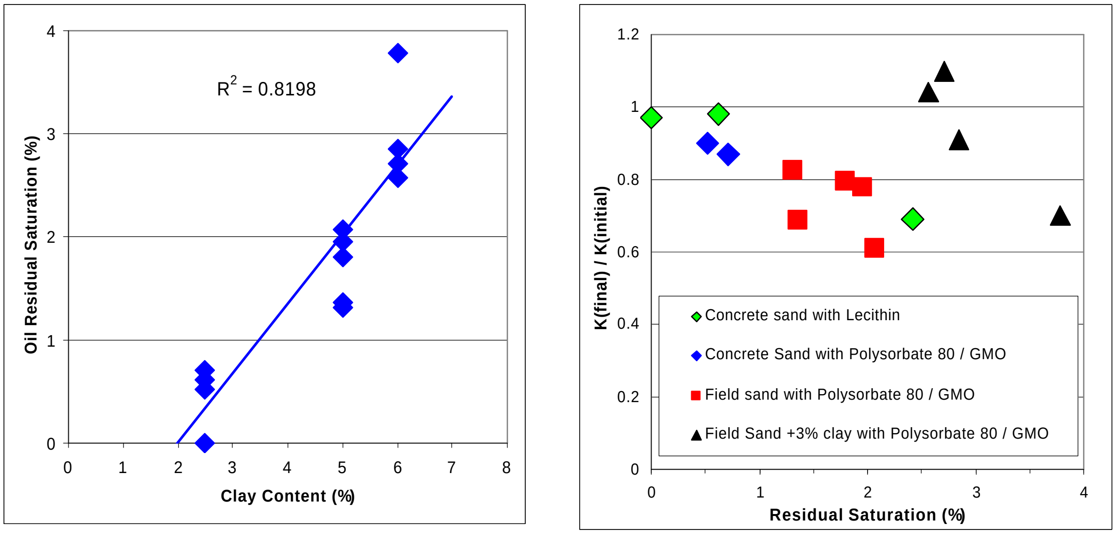

Figure 4 Experimental results from laboratory permeameter experiments. Sediment treated with 3 pore volumes (PV) of emulsion followed by > 8 PV of chase water.

Altus AFB Pilot Test

At Altus Air Force Base (AFB), OK, a pilot-study is being conducted to evaluate the suitability of EOS® injection for stimulating reductive dechlorination of TCE. Historical releases of degreasing agents resulted in a 5000-ft long chlorinated solvent plume with TCE concentrations reaching 78,000 µg/L in the source area. Geology at the site consists of reddish-brown, moderately plastic, sandy clay to a depth of roughly 15 ft, underlain by fractured clayey shale with occasional gypsum layers. The depth to ground water is 8-10 ft below ground surface (bgs). Most ground-water flow and contaminant transport appears to occur through a series of weathered shale fractures located immediately beneath the surficial clay and within a thick gypsum layer approximately 35 ft below grade.

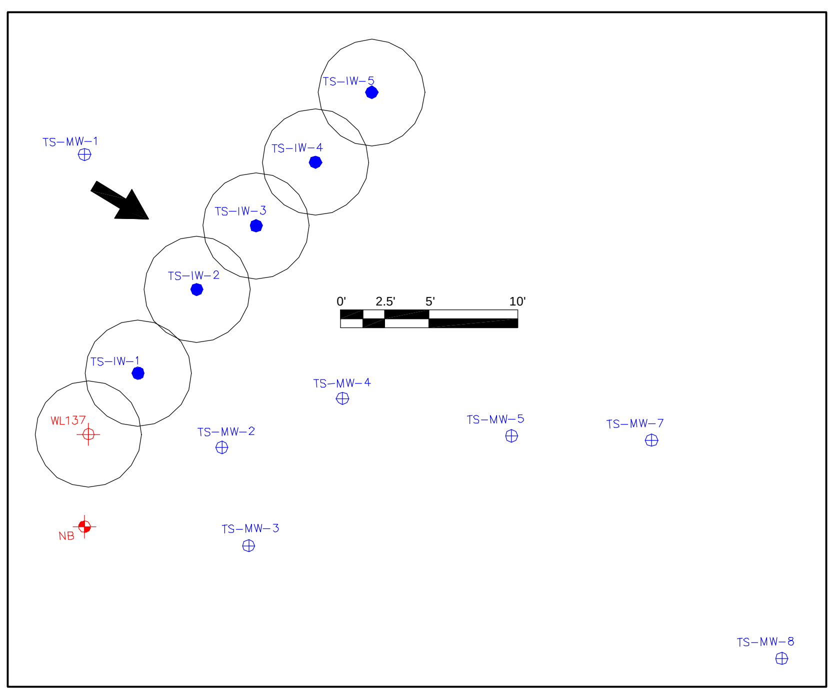

Figure 5 Altus AFB injection and monitor well layout

The pilot study is evaluating the use of EOS® as a low-cost carbon source for controlling chlorinated solvent migration through enhanced anaerobic bioremediation. A line of six permanent 2-inch PVC wells spaced 5 ft apart was installed perpendicular to ground-water flow approximately 250 ft downgradient from the source area. Over a 4-day period in December 2001, a mixture of emulsified soybean oil, yeast extract, and lactate was injected through each well to form a 30-ft wide EOS® barrier that would stimulate reductive dehalogenation. Each injection was planned to treat a 6-ft diameter area to provide a small overlap between each injection point. The wells were screened from 8 to 18 ft bgs to achieve maximum distribution of the treatment mixture in the upper weathered fracture zone.

Monitoring of adjoining wells during the injection process showed that EOS® had reached a monitor well 20 ft from the injection wells, but several closer wells in less permeable zones received little substrate. In injection well TS-IW-3, TCE concentrations dropped immediately after injection due to sorption to the oil. However by August 2002 (7.5 months after injection), total ethenes (molar concentration) in this well had recovered to over 90% of the pre-injection concentration indicating that sorption to the oil was no longer significant. Over the 13-month interval since EOS® injection, TCE has declined from 1300 µg/L to below the detection limit (BDL) in the center injection well. In a well 20 ft downgradient of the barrier (TS-MW-5), TCE has declined from 1,600 µg/L to BDL, cDCE from 900 to 73 µg/L, with increases in VC from 440 to 1,770 µg/L and ethene from 6.9 to 510 µg/L. More than eight months after the EOS® injection, high levels of organic carbon (> 100 mg/L) were still present in this well suggesting the potential for continued biodegradation of VC. Results from this pilot test are also being used to evaluate the application of edible oils for full-scale remediation at Altus AFB.

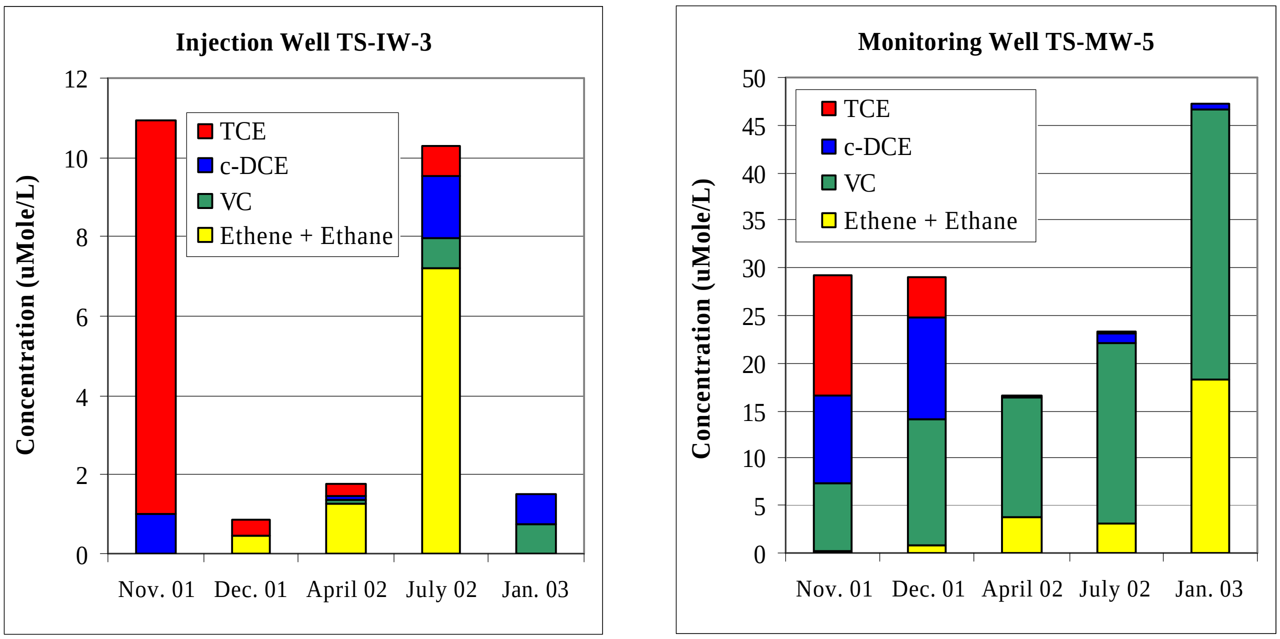

Figure 6 **Monitoring results from an injection well (TS-IW-3) in center of barrier and a monitor well (TS-MW-5) located 20 ft downgradient of barrier.**

Edible oil emulsions are now being used in pilot-studies and full-scale remediation projects at six sites for controlling groundwater impacts associated with chlorinated solvent releases. An analysis of total costs over a 30 yr life cycle suggest that edible oil barriers may be a very cost effective alternative for controlling plume migration. Additional work is now underway to evaluate the use of edible oils for treatment of other pollutants including nitrate, perchlorate, chromium, radionuclides, and acid mine drainage.